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Effects of Artificial Destratification on
Distribution of Bottom Organisms
in El Capitan Reservoir

By
INLAND FISHERIES BRANCH

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1970

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ABSTRACT

The bottom fauna of El Capitan Reservoir, San Diego County, California, was sampled during 1964, under normal conditions, which included prolonged stratification. The lake was then destratified artificially for 2 years. The benthic organisms, including midge larvae and pupae, oligochaete worms, nematode worms, and freshwater clams, rapidly invaded the profundal zone. They had previously been absent there in summer. Their total numbers in the lake increased dramatically. A combination of anoxia and toxic conditions in the hypolimnion had presumably excluded them from the deeper parts of the lake when it was stratified.

In 1967 the lake was permitted to stratify again. By August the normal summer distributional pattern of bottom organisms was beginning to reappear.

Extending the distribution of midges throughout the lake by artificial destratification should increase the amount of food available to game fish. This is not so with oligochaetes, clams, and nematodes, which do not usually enter the food chains culminating in game fish. The long-term implications of artificial destratification for reservoir fishery management are discussed.

EFFECTS OF ARTIFICIAL DESTRATIFICATION ON DISTRIBUTION OF BOTTOM ORGANISMS IN EL CAPITAN RESERVOIR¹

by

INLAND FISHERIES BRANCH²

INTRODUCTION

Destratification of lakes and reservoirs by compressed air injection is feasible and often improves domestic water quality (Nickerson, 1961; Ford, 1963; Ogborn, 1966; Fast, 1968). This is expected to become an increasingly common practice on many waters which are also used for public fishing. To determine the impact of destratification on reservoir ecology, the California Department of Fish and Game initiated a study at El Capitan Reservoir, San Diego County. Part of the study concerned the effects of artificial destratification on the distribution of bottom organisms, and these results are described in this report.

El Capitan Reservoir contains the usual California assemblage of warmwater fishes (Fast, 1968). The bottom fauna consists mainly of chironomids, tubificids, clams, and nematodes. Under normal summer conditions, the reservoir is sharply stratified, and a warm, aerobic epilimnion overlies a cool, anaerobic hypolimnion. Artificial destratification made temperature and oxygen concentrations relatively uniform (Fast, 1968).

The reservoir rose 10 m during the study period (Table 1). This probably caused the changes observed in collections from the littoral zone. Fortunately, these peripheral changes did not mask the broad changes in the profundal zone associated with destratification.

TABLE 1
Changes in Surface Elevation and Volume of El Capitan Reservoir
During the Study Period

	Gage (m)	Change from previous year (m)	Total volume (acre ft)
July 27, 1964.....	24.8	----	9,200
July 28, 1965.....	29.1	+4.3	15,100
July 15, 1966.....	32.4	+3.3	20,500
August 2, 1967.....	33.3	+0.9	21,845

¹ This work was performed as part of Dingell-Johnson Project California F-23-R, "The Effects of Artificial Destratification on Lake Fisheries", supported by Federal Aid to Fish Restoration funds.

² This report was written by Alex Calhoun and Paul Hubbell, and is based upon data from a program planned and conducted by Arlo W. Fast. Mr. Fast is now engaged in graduate studies at Michigan State University, East Lansing, Michigan. Emmitt McClendon made most of the calculations. Cliffla Corson drew the figures. Stephen J. Nicola and John W. Emig helped with editing. William Richardson, Lee Miller, Scott Soule, Marvin Whalls, James Ryan, and Leonard Fisk also contributed to the project. The San Diego Utilities Department, the Helix Irrigation District, and San Diego County were cooperators in this project and all made important contributions.

METHODS

The benthos was sampled before, during, and after artificial destratification. Collections were made during the following periods: June 1-2, June 29-30, July 26-28, August 31-September 1, 1964; January 30-31, May 27-28, June 30-July 1, July 28-29, September 1-2, 1965; January 31-February 3, July 15, 1966; and August 2-4, 1967. In this report, these periods are represented by the following respective dates: June 1, June 30, July 27, August 31, 1964; January 30, May 27, June 30, July 28, September 1, 1965; January 31, July 15, 1966; and August 2, 1967. Three transects (Figure 1) were sampled during each period, except for July 15, 1966, when only transect 1 was sampled. Usually three samples were taken from each 2-m depth interval with an un-screened Ekman dredge 15 cm square (225 cm^2).

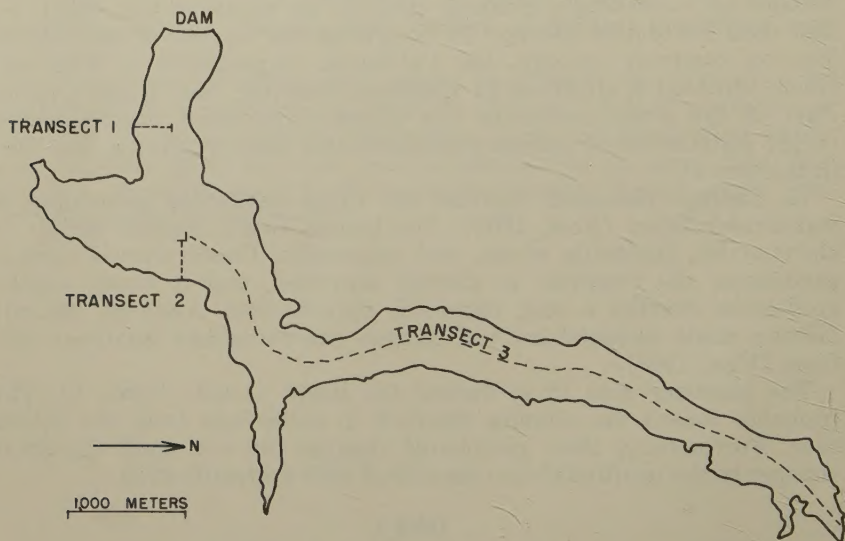


FIGURE 1. Map of El Capitan Reservoir, showing benthos sampling transects.

All samples were partially sorted in the field with a U.S. sieve series number 30 (0.58 mm mesh opening) sieve and then preserved in 10% buffered formalin. Anderson's (1959) sugar flotation method was modified (360 g sugar per liter) and was used to extract organisms other than clams from shallow samples, which generally consisted mainly of sand and gravel. Counts of 15-ml subsamples of floated materials were then extrapolated to estimate sample totals. Deeper samples containing mainly colloidal materials were sieved and all organisms counted.

The year 1964 served as a control. In 1965 and 1966 the reservoir was destratified artificially. Then it was permitted to stratify again in 1967, to provide a second control.

We were unable to relate the abundance of bottom organisms to the physical characteristics of the substrate.

All curves were fitted by eye.

RESULTS

Changes in Distribution of Chironomid Larvae

The midge fauna is limited. Larvae and pupae reared to adults were identified as *Chironomus attenuatus*, *Procladius bellus*, *P. denticulatus*, and *Tanytarsus* spp.³ They were grouped into a single category in our samples (Appendix I).

Under stratified conditions in 1964, midge larvae were virtually absent below 10 m by July (Figure 2). On January 30, 1965, following the fall overturn, they were more abundant in deeper water, although few occurred below 15 m (Figure 3).

The lake began to stratify again in mid-March of 1965. Distributional patterns on May 27 and June 30 that year, during the early part of the period of normal stratification, resemble the comparable ones for 1964, but with higher densities (Figure 4). Air injection from June 10 through June 21 and from July 1 through October 4 kept the reservoir mixed for the rest of the summer.

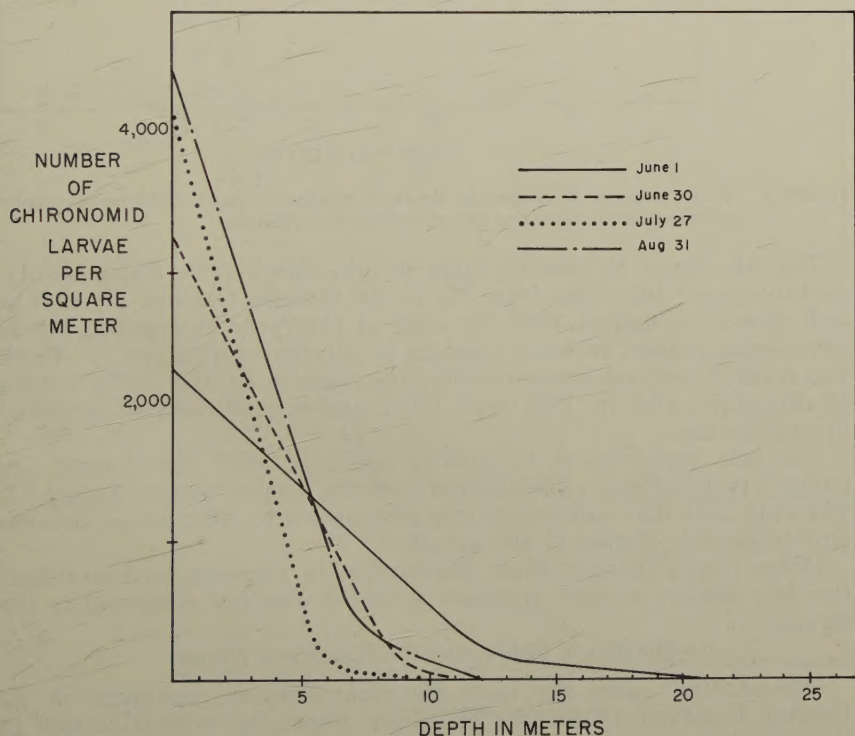


FIGURE 2. Densities of chironomid larvae in relation to depth during summer stratification, 1964.

By September midge larvae had invaded the deeper water down to 25 m in substantial numbers (Figure 4). This condition persisted as long as the profundal zone remained aerobic.

³ Identification by Gail Grodhaus, California Department of Public Health, Berkeley, California, assisted by Harvey Magy and Donald L. Rohe.

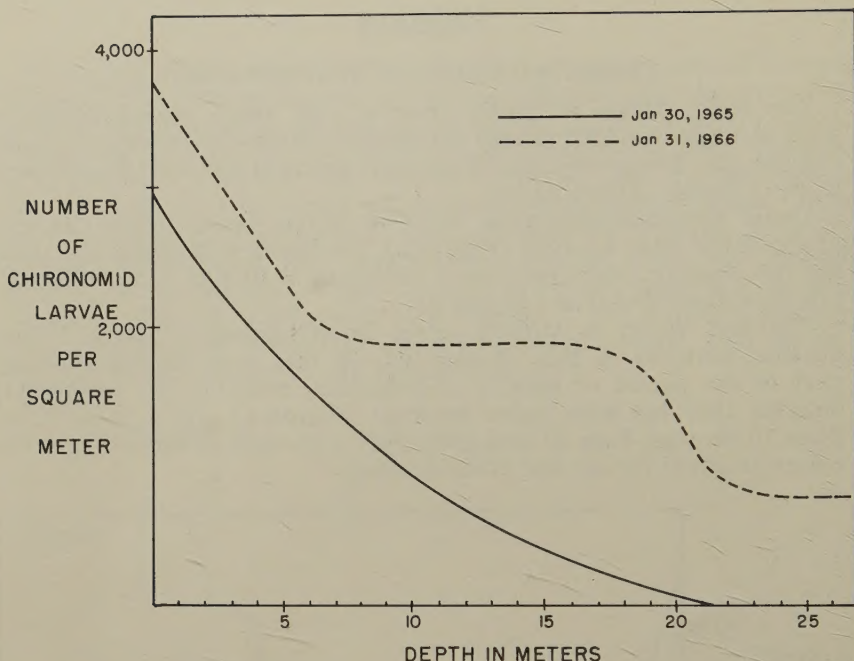


FIGURE 3. Winter densities of chironomid larvae in relation to depth, following a summer of normal stratification and one of artificial destratification.

The lake began to stratify again in mid-March 1966. Subsequently, continuous air injection, from March 19 through October 17, kept it well mixed throughout 1966. By July of that year chironomid larvae were again present in some numbers at all depths (Figure 5). There was marked contrast between midge distribution in July 1964, during stratification, and in 1965 and 1966, under conditions of artificial destratification.

The lake was allowed to stratify again in 1967. By August the midge larvae had again disappeared from the deeper waters (Figure 5). The July 1966 data are not strictly comparable to other series, because only transect 1 (Figure 1) was sampled.

Midge pupae changed their distribution in response to destratification in a similar manner. Numbers collected were few compared to the larvae.

Changes in Distribution of Oligochaete Worms

Oligochaetes⁴ were the most abundant benthic organisms in El Capitan Reservoir (Appendix II). They responded to stratification in the same general way as the midge larvae (Figure 6). In January 1965, following prolonged stratification the preceding summer, numbers remained very low below 10 m, although a slow reinvasion of the deeper parts of the lake had begun after the fall overturn (Figure 7).

⁴R. O. Brinkhurst, University of Toronto, Toronto, Canada, identified selected samples of oligochaetes as: *Limnodrilus hoffmeisteri*, *Bothrioneurum vejdoskyanum*, *Euliyodrilus bavaricus*, *E. hammoniensis*, and *Tubifex tubifex*. We did not attempt to assess the relative abundance of the different species in our samples. *L. hoffmeisteri* was by far the most abundant among those examined by Dr. Brinkhurst.

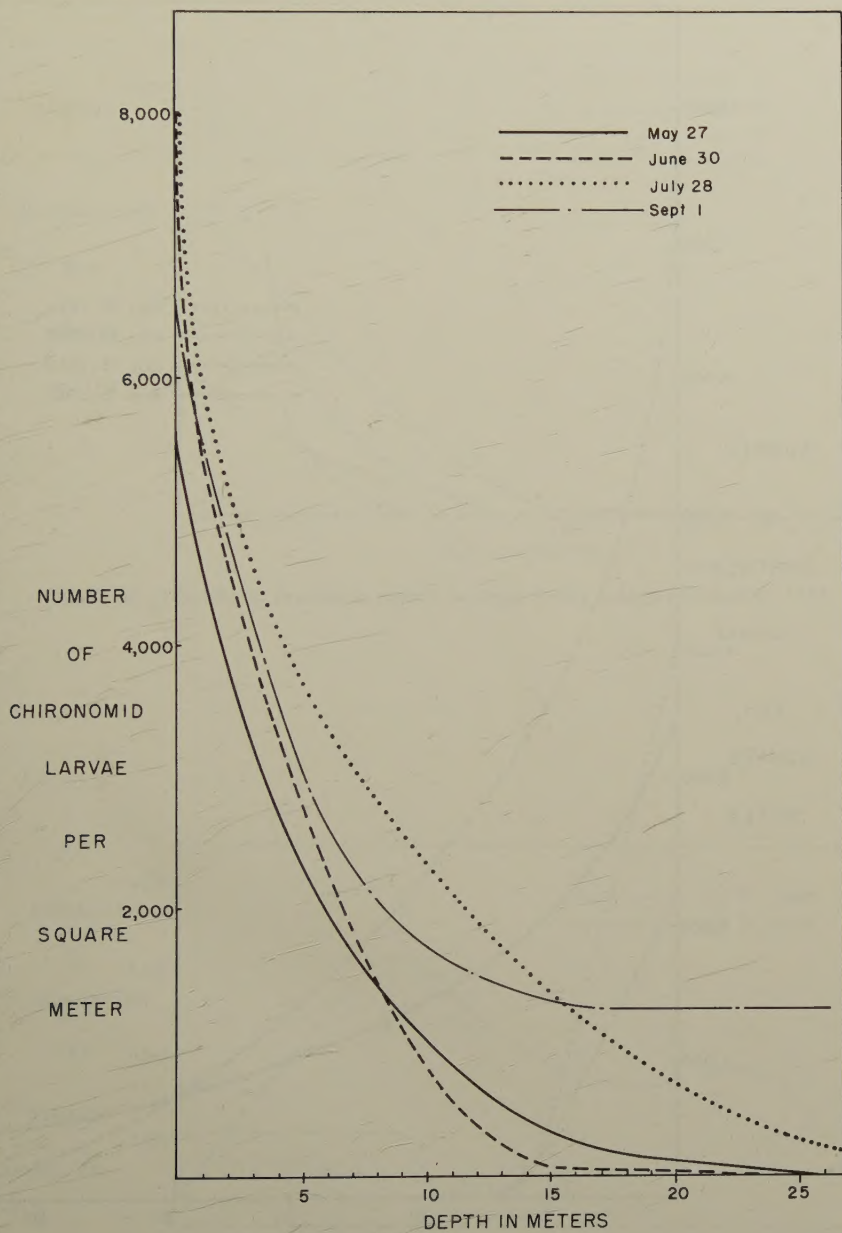


FIGURE 4. Densities of chironomid larvae in relation to depth during summer 1965.

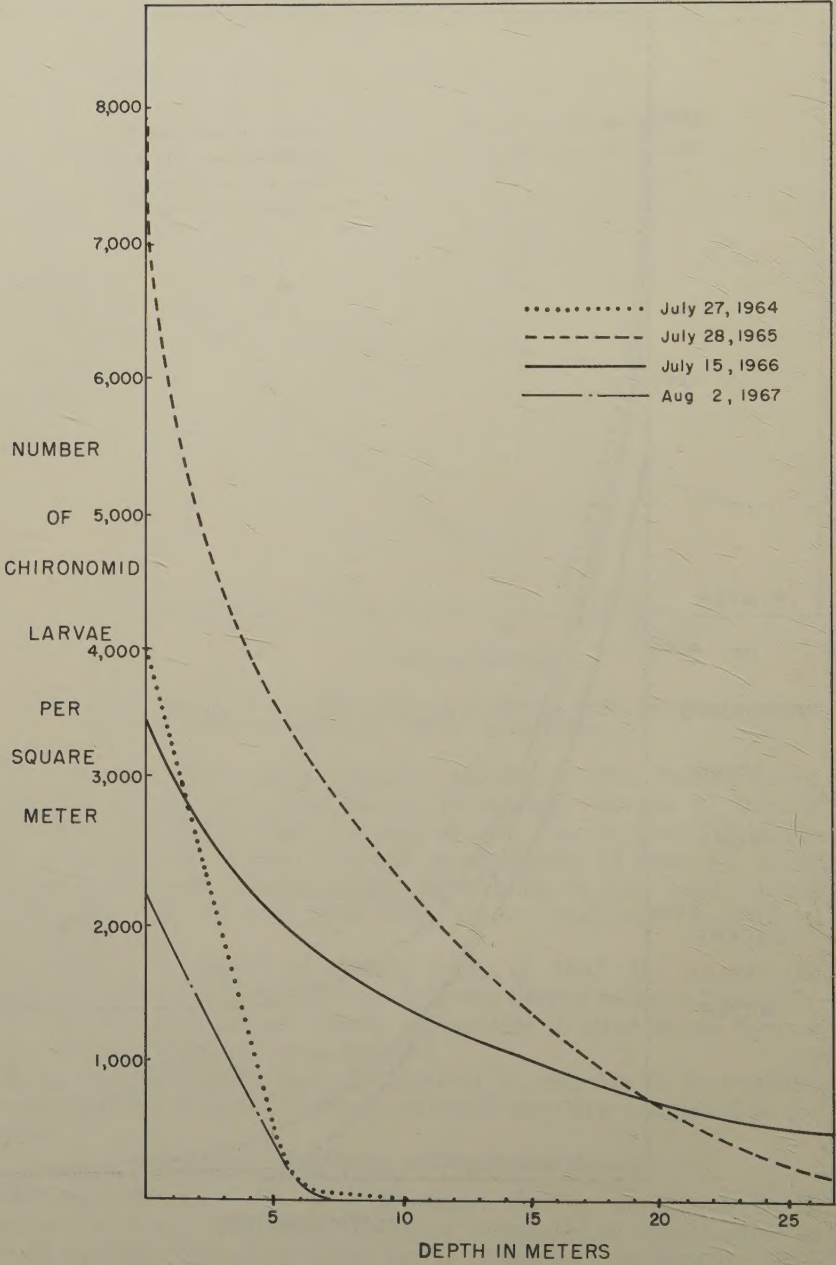


FIGURE 5. Summer distributions of chironomid larvae during a period of normal stratification, after about 6 weeks of artificial destratification, after a full year of destratification, and after stratification was again permitted to develop.

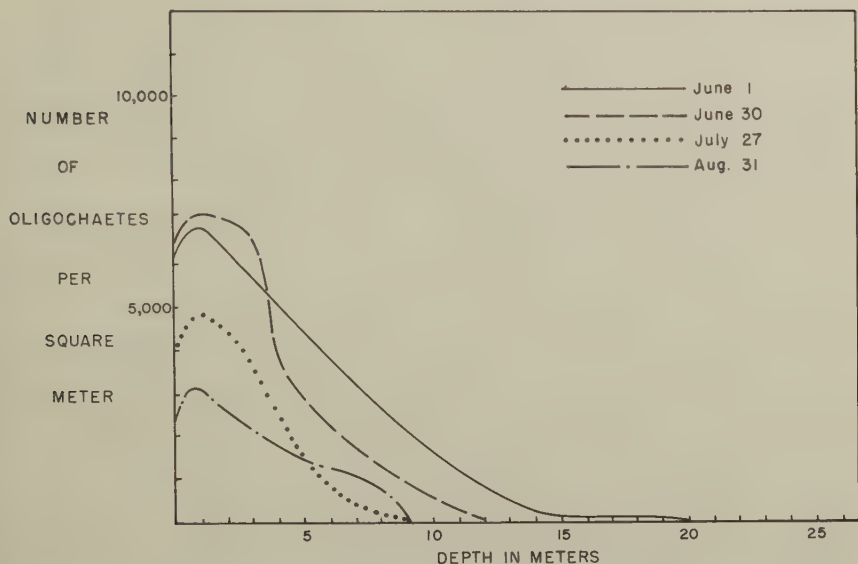


FIGURE 6. Oligochaete densities in relation to depth during summer stratification, 1964.

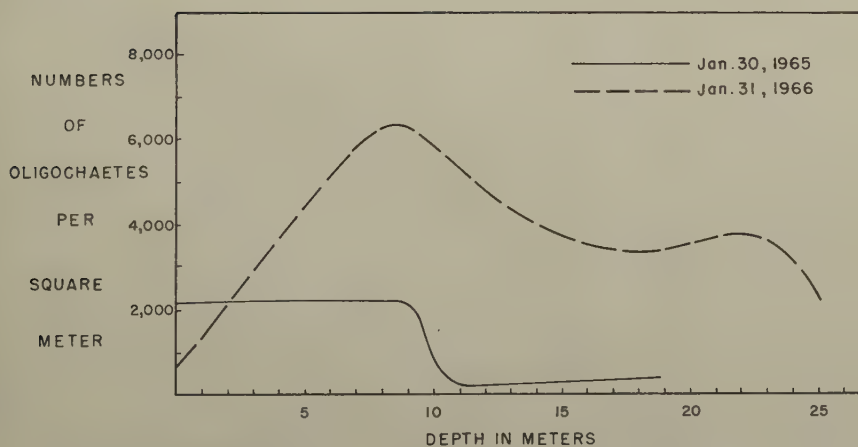


FIGURE 7. Winter oligochaete densities in relation to depth after a summer of normal stratification and after one of artificial destratification.

The artificial destratification in late June 1965 apparently induced an oligochaete population explosion. They became more abundant generally, and had invaded the profundal zone in only 4 weeks (Figure 8). Previously, the population had remained relatively static during May and, following aeration in July, it again became static (Figure 8). The oligochaetes responded more rapidly and more dramatically than the chironomid larvae.

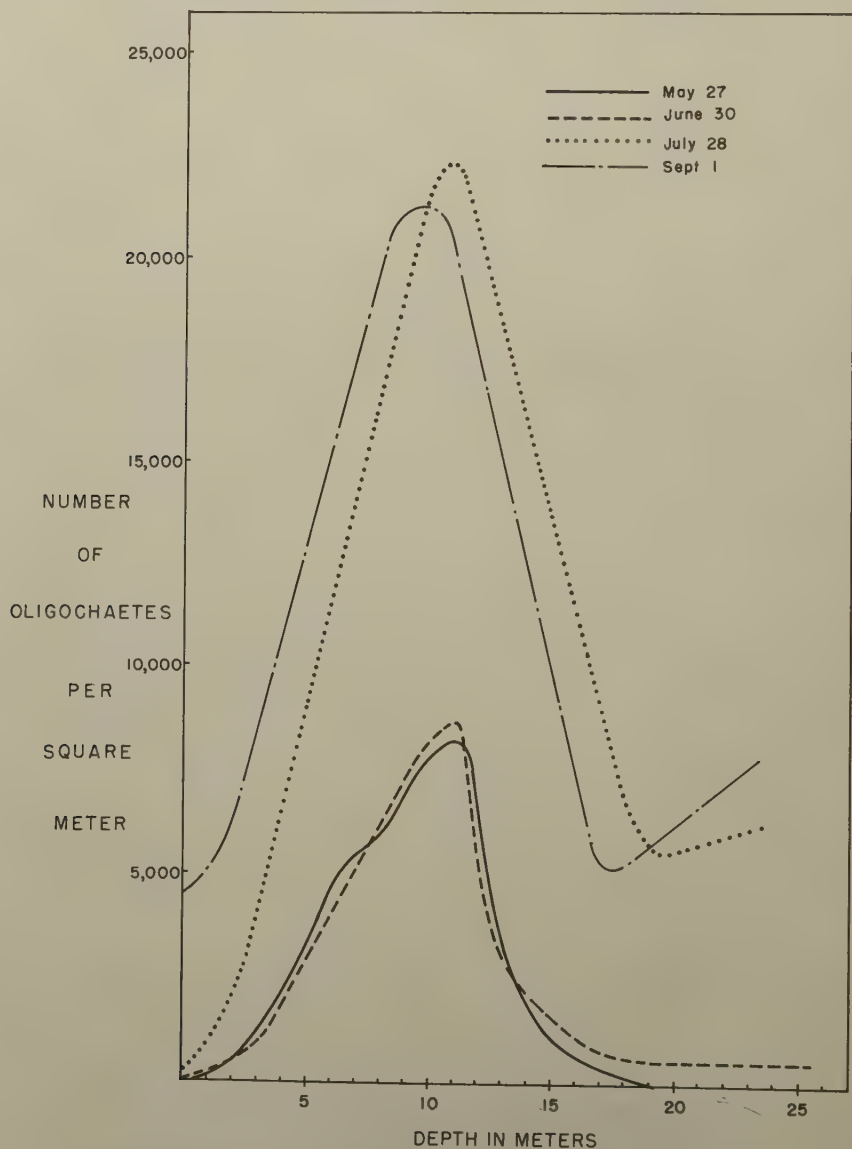


FIGURE 8. Oligochaete densities in relation to depth during summer 1965.

The winter distribution and abundance of these organisms also changed radically after a summer of destratification (Figure 7).

In 1964, when the lake was normally stratified, oligochaetes were present only in areas shallower than 10 m (Figure 9). In 1965, following destratification, they occurred in large numbers at all depths. In 1966, following a full year of destratification, the normal summer distri-

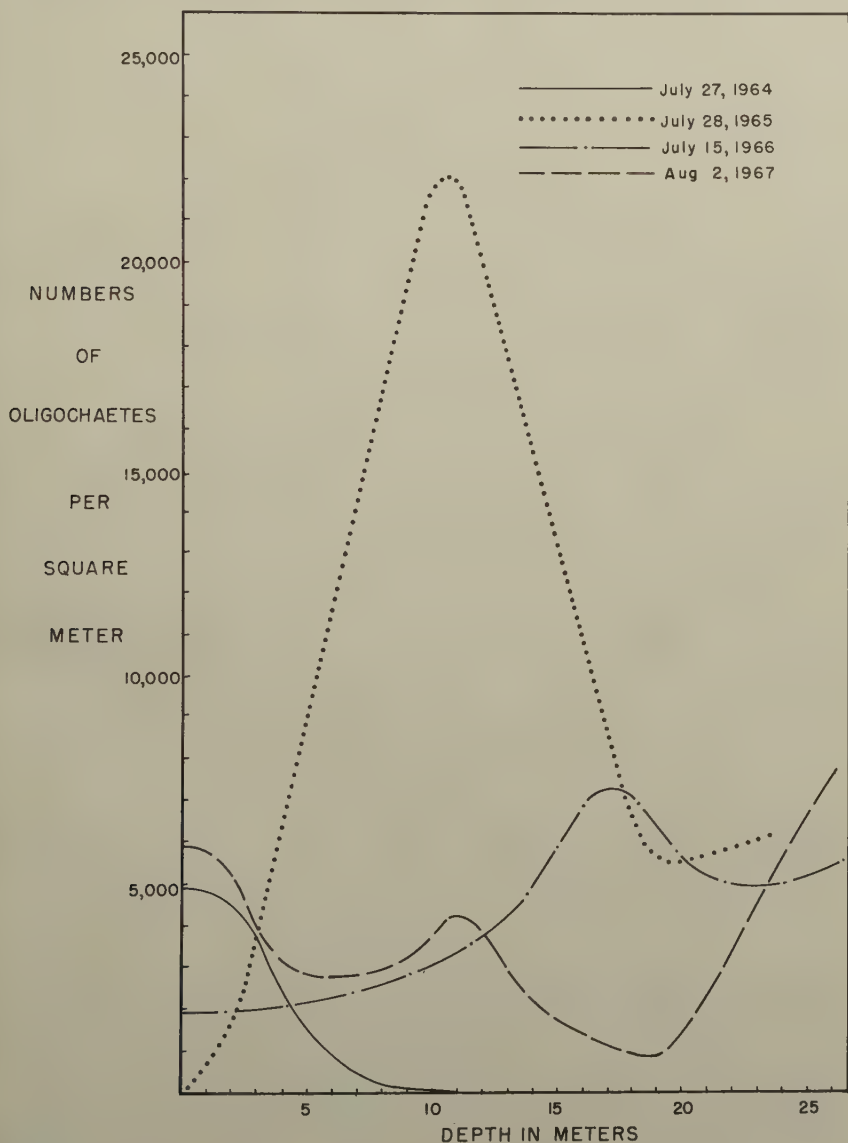


FIGURE 9. Summer oligochaete densities during a period of normal stratification, after about 6 weeks of destratification, after a full year of destratification, and after normal stratification was again allowed to develop.

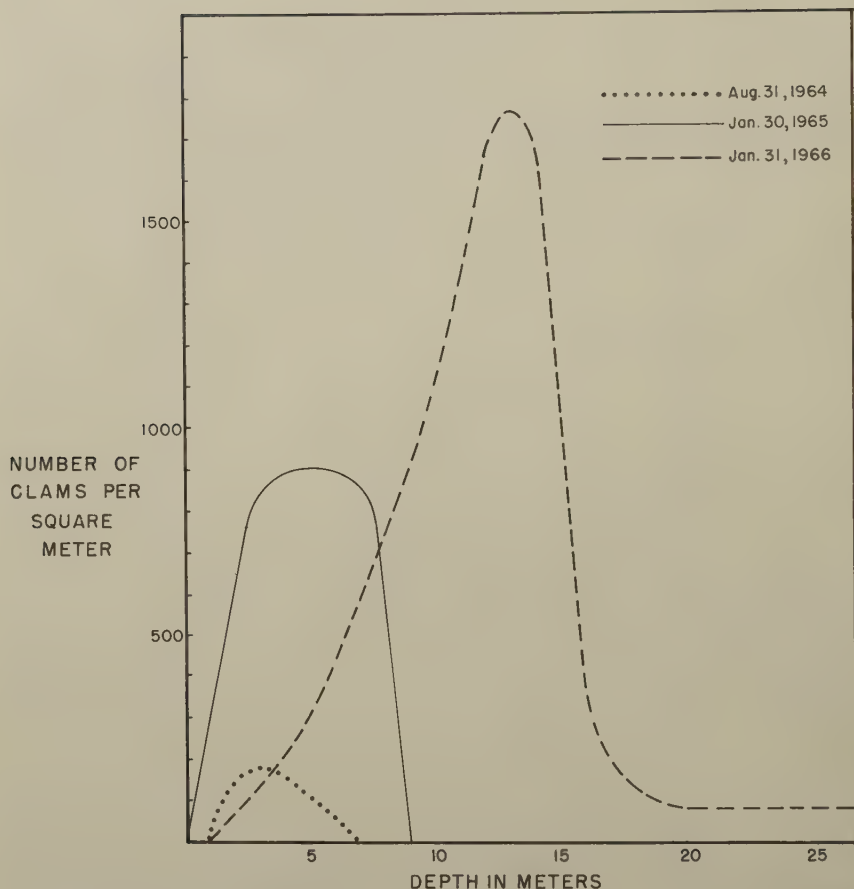


FIGURE 10. Winter clam densities in relation to depth after a summer of normal stratification and after the lake had remained unstratified for 12 months. The newly developing population present in 1964 is also represented.

bution was reversed, with highest concentrations in the deeper parts of the reservoir. In 1967 the oligochaetes were surviving in the hypolimnion better than the midge larvae (Figure 5).

The reasons for these distributional changes are discussed later.

Changes in Distribution of Clams

The Asiatic clam (*Corbicula manillensis*)⁵ apparently invaded the reservoir as veligers in imported Colorado River water shortly before the study began. During 1964 they were too sparse to relate their distribution to limnological conditions (Appendix III). The population exploded in the littoral zone between August 31, 1964, and January 30, 1965 (Figure 10). In late May 1965 the situation was much as it had been in January. As 1965 progressed, the clams decreased in density and began to appear in the newly flooded littoral area (Figure 11).

⁵Identification by William J. Clench, Museum of Comparative Zoology, Harvard University, Cambridge, Massachusetts.

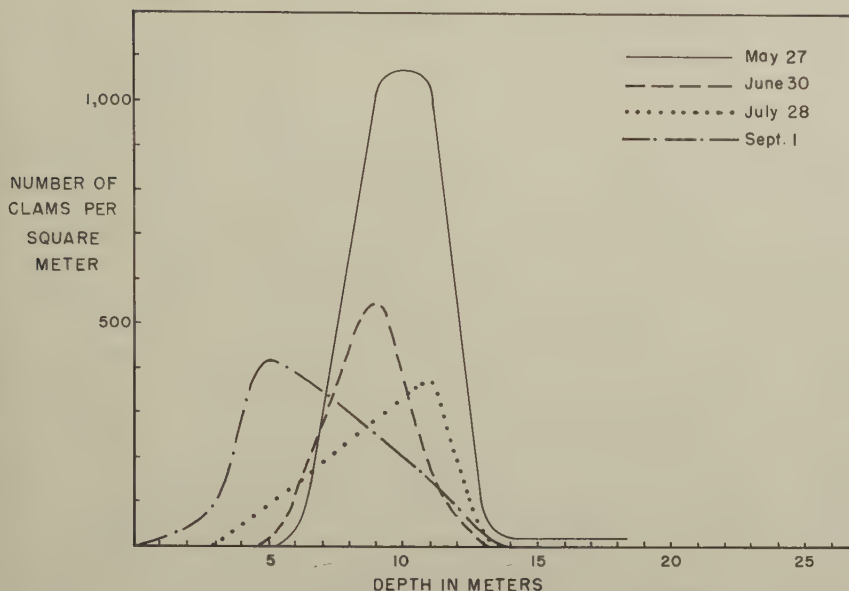


FIGURE 11. Clam densities in relation to depth in summer 1965.

They did not appear in the profundal zone, where conditions were suitable, until January 1966 (Figure 10).

In 1965 the lake began to stratify in mid-March and was not destratified until late June. This apparently prevented the clams from colonizing areas below the thermocline (Figure 11). Conversely, in 1966, after the lake had remained destratified for a year, clams occurred throughout the lake by July (Figure 12). In August 1967, with stratification restored, there were still substantial numbers in the deep areas (Figure 12).

Changes in Distribution of Nematodes

Nematodes also responded dramatically to artificial destratification by increasing rapidly in numbers (Appendix IV). During the summer of 1964, when the lake was stratified, sparse populations existed in areas shallower than 10 m (Figure 13). The right-hand peak in the curve for August 31 represents a single series of three samples from transect 2 taken at a depth of 12 to 14 m.

The same general pattern of distribution continued through June 1965. However, between June 30 and July 28 the population exploded dramatically. Densities were still high a month later and nematodes were present throughout the profundal zone, although numbers were low in the deeper areas (Figure 14).

By July 1966, following a year of destratification, the nematode populations had dwindled materially compared with those a year earlier (Figure 15). A year later with the lake stratified again, these organisms had virtually disappeared (Figure 15).

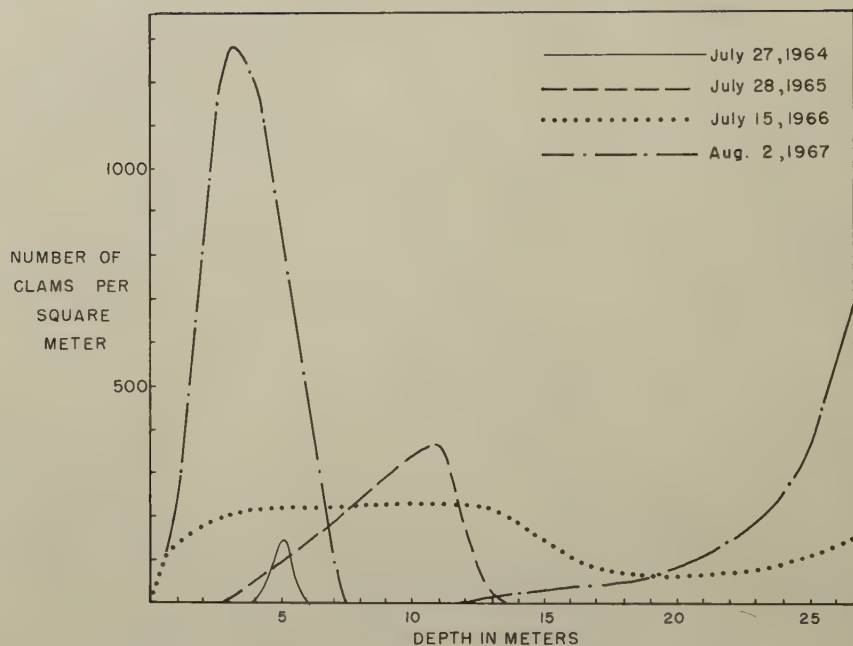


FIGURE 12. Summer clam densities in relation to depth, 1964-1967.

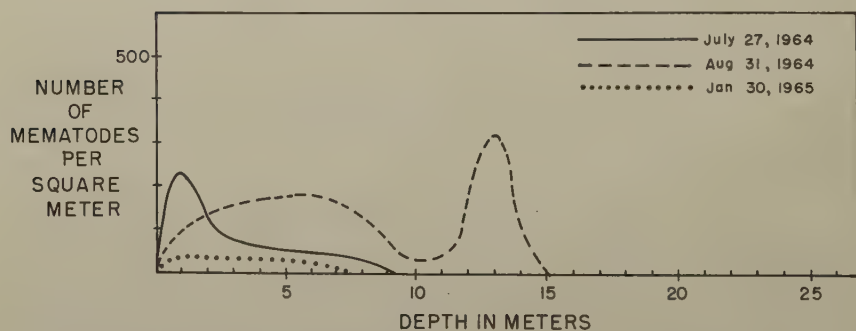


FIGURE 13. Nematode densities in relation to depth during a summer of normal stratification and the following winter.

DISCUSSION

Distributional Changes in Relation to Environmental Conditions

The sharp decline in abundance of bottom organisms generally as the depth increased, and their virtual absence below about 10 m during times of stratification, indicates lethal conditions for these organisms in the bottom muds. Eggleton (1931) emphasized the "need for great caution in pointing out any single factor as the sole determining influence in the abundance and distribution of bottom animals."

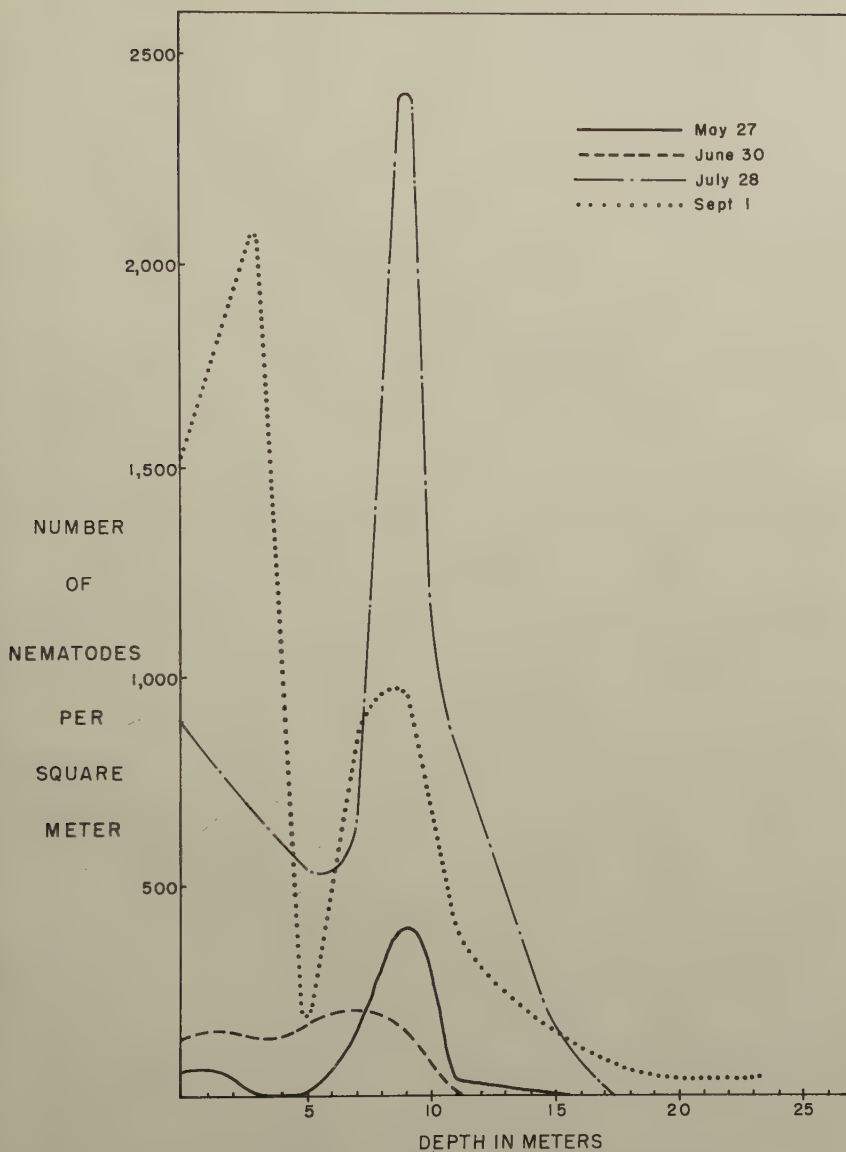


FIGURE 14. Nematode densities in relation to depth during 1965.

A combination of anoxia and toxic chemical conditions, rather than anoxia alone, seems to be the best explanation.

Larvae of different species of midges vary in their ability to tolerate anaerobic conditions (Augenfeld, 1967). However, *Chironomus attenuatus* and *Procladius bellus*, both present in El Capitan Reservoir, can apparently do so for prolonged periods (Curry, 1965), like some oligochaete worms (R. O. Brinkhurst, per. comm.). Chemical anal-

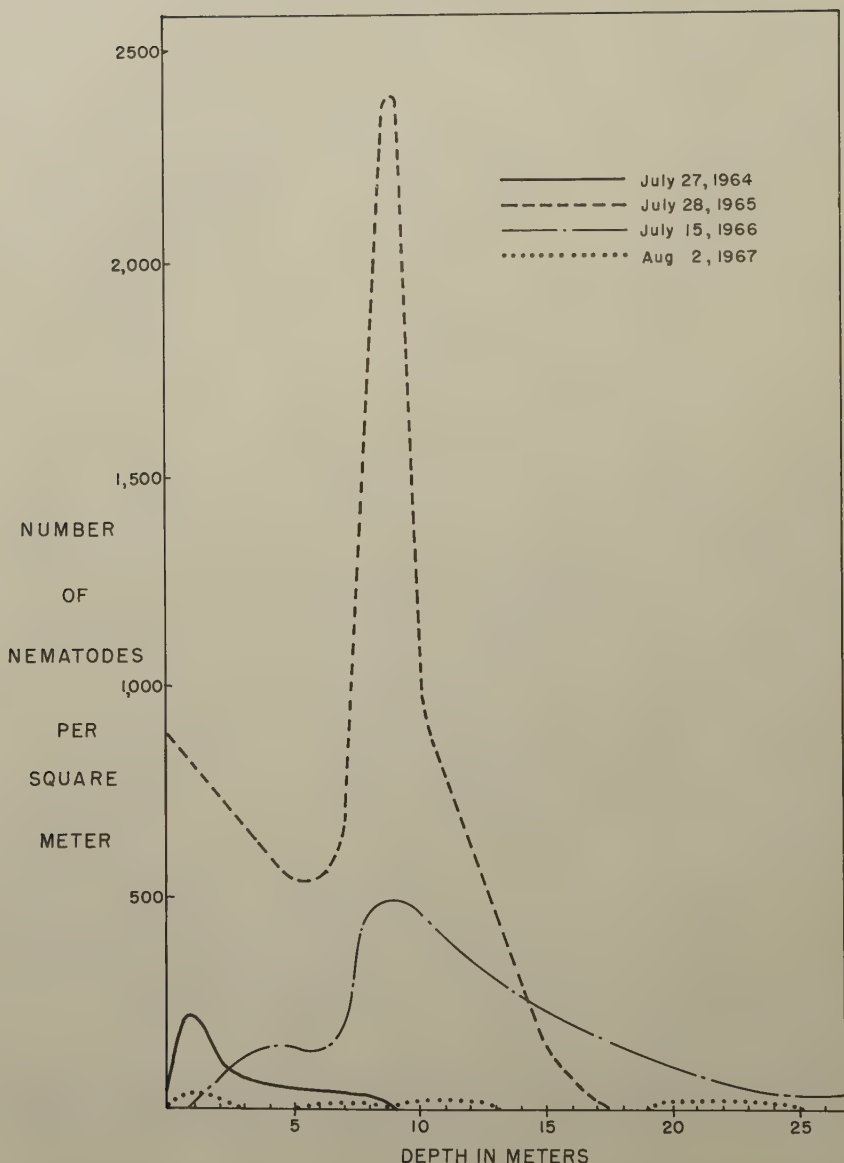


FIGURE 15. Summer nematode densities during the period of normal stratification, after 6 weeks of destratification, after a full year of destratification, and after stratification was again allowed to develop.

yses of water samples taken from a depth of 17 m revealed high iron and manganese levels during stratification (Fast, 1968). For example, on August 5, 1964, iron levels at the surface and at 17 m were 0.02 and 0.39 mg per liter, respectively. Comparable manganese figures were 0 and 1.07 mg per liter. These data imply high levels in the bottom muds.

In a recent review of the ecological requirements of midges, Curry (1965) concludes that little is known about them. Nevertheless, he indicates that very low concentrations of iron (Fe^{++}) are toxic to some species. Hydrogen sulfide may also have contributed to the toxicity. Fast (1968, p. 62) notes,

"Although we did not analyze for hydrogen sulfide, artificial destratification limits this substance. Seventeen-meter water samples during the summer 1964, were clear when first collected. After they set a few minutes they turned a milky white color due to elemental sulfur formation. The samples had a pronounced rotten egg odor, attesting to high hydrogen sulfide concentrations. I did not detect these odors during either 1965 or 1966. Aeration prevented the accumulation of this substance. The rotten egg odor again became pronounced during the summer, 1967, following several months of hypolimnion stagnation."

In reviewing the biology of the Tubificidae, Brinkhurst (1965) emphasizes the lack of information on the subject. He further states, "The distribution of species in lakes makes no sense in terms of abiotic factors in the environment." He mentions a possible correlation between the numbers of worms and the amount of organic materials present in stream sediments. E. C. Bay (per. comm.) found densities of midge larvae to be correlated with amounts of food in the substrate.

However, Brinkhurst points to the lack of such a correlation for worms in Lake Maggiore. Further, he points to a paucity of information about the oxygen requirements of various tubificids. Some can survive very low concentrations for considerable periods. Subsequently (per. comm., 1969) he mentioned that worms can survive for more than 4 months in totally anoxic lake bottoms.

The dramatic increase in the worm population a few weeks after artificial destratification began in 1965 apparently represents a spring reproductive burst, commonly seen in these animals under highly favorable conditions (Brinkhurst, per. comm.). Higher temperature, ample oxygen and food, and disappearance of the toxic conditions associated with stratification may all have contributed. Eggleton (1931, p. 297) interprets similar increases as follows,

"The tubificids in Douglas Lake were rarely found sexually mature during the summer. In October, 1928, however, many sexually mature specimens and a few cocoons were collected in bottom samples. Third Sister Lake yielded many sexually mature specimens and some cocoons each year in November. However, from February to the middle of April, each year, was the period when the largest proportion of sexually mature worms was collected and also during that period the greatest numbers of cocoons were taken. Following the appearance of the cocoons there was always a great increase in the total numbers of tubificids and many of these worms were small and immature. These periods of reproduction correspond with and explain their large numerical increases in Third Sister Lake.

It seems probable that the greatest effect of the overturns on the *Tubificidae* is an acceleration of sexual maturity and activity, since these periods of circulation coincide roughly with the periods of maximum occurrence of cocoons and since the experiments described previously appear to show that some tubificid cocoons may develop even during stagnation within the profundal zone."

According to Brinkhurst, (per. comm.) "... *Most* species seem to mature in their second year and probably die after this. The pollution-tolerant species are very erratic in their breeding behavior, and populations may increase or decrease very rapidly. ... Cocoons take a couple of weeks to develop, but the resulting offspring are very small." Information on the comparative sizes of worms in the June and July 1965 samples to clarify this point is unfortunately lacking.

The subsequent events through August 1967 are also consistent with this theory of a sudden reproductive burst in July 1965 followed by high mortalities after the environment became saturated. For the lake as a whole, mean oligochaete densities⁶ declined steadily during the summer of 1964 as conditions in the hypolimnion deteriorated. After the fall overturn, densities began to rise again, regaining the levels of June 1964 the following May. Aeration began on June 10, 1965. Then, instead of declining as they had when the lake was stratified, mean densities had more than tripled by September 1965, reaching 12,000 organisms per m², compared to about 3,500 the preceding June, and about 1,250 in August 1964 (Figure 16). Midges followed a similar trend (Figure 17).

The dramatic response of tubificids to abiotic changes caused by artificial destratification is apparently a rather unusual occurrence (Brinkhurst, 1965; Kennedy, 1965; Brinkhurst and Walsh, 1967).

The population explosion of nematodes 7 weeks after destratification began (Figure 14) is not surprising in view of the important roles food and oxygen play in controlling their distribution (Crofton, 1966) and their short generation time. In the latter connection, laboratory cultures of nematodes isolated from a water treatment plant reached maximum populations of 115,000 individuals in 20 ml of medium in just 10 days, with generation time varying from 2 to 15 days, depending on temperature and species, in parallel experiments (Pillai and Taylor, 1968). The bimodality of the July and September curves in Figure 14 may represent two distinct population bursts, one in the newly flooded littoral area, and the other centering around 10 m in a zone which now provided ideal temperatures and ample oxygen, and was presumably

⁶Fast (per. comm.) describes his procedures for deriving density and total population estimates as follows:

"Total zoobenthos population sizes were calculated for each collection period. Average organism densities per square meter for each depth interval were calculated, and the values obtained were multiplied by the estimated bottom area in square meters in that interval.

"Bottom areas in each depth interval were estimated by taking the difference in the reservoir's surface areas between the top and bottom of each depth interval. This gives an underestimate of the bottom area, but should provide a good relative estimate of the bottom area in that interval.

"Estimated population sizes at each depth interval were summed to yield an estimate of the total zoobenthos population in the reservoir. The total population size was divided by total reservoir area to ascertain the average population density. This statistic is weighted by depth, since progressively smaller total areas result with increasing water depth."

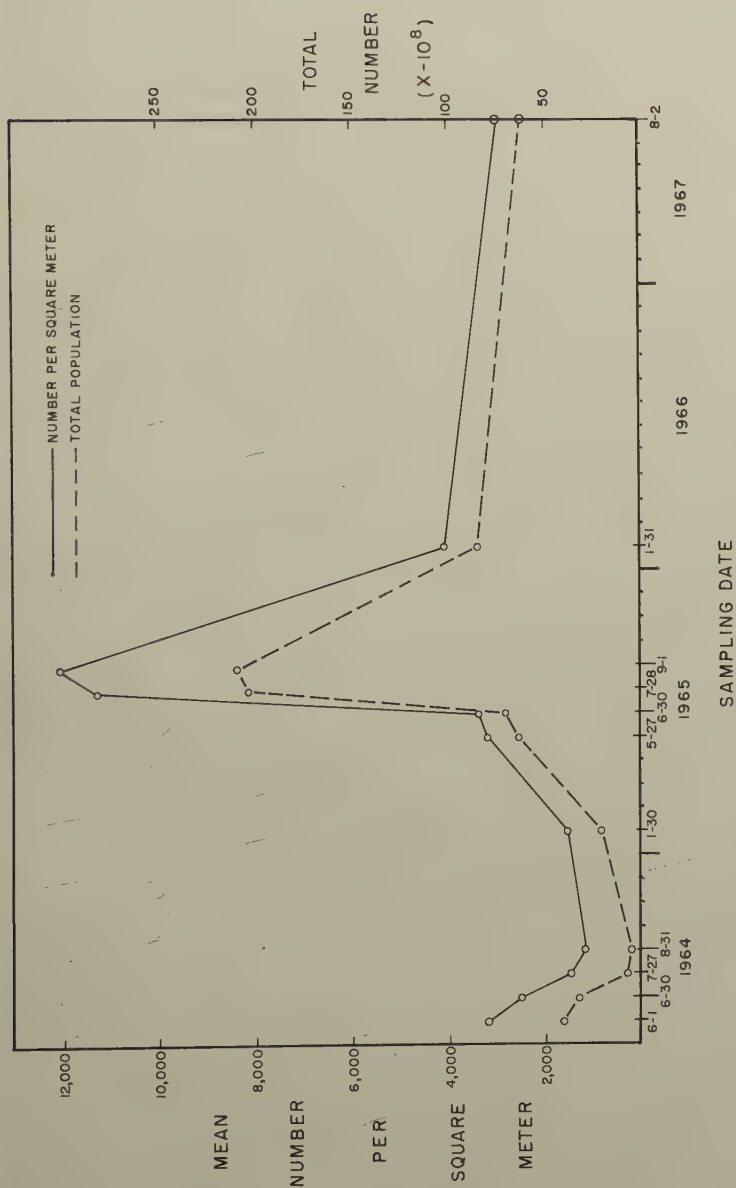


FIGURE 16. Estimated total numbers and mean densities of oligochaetes for the entire reservoir.

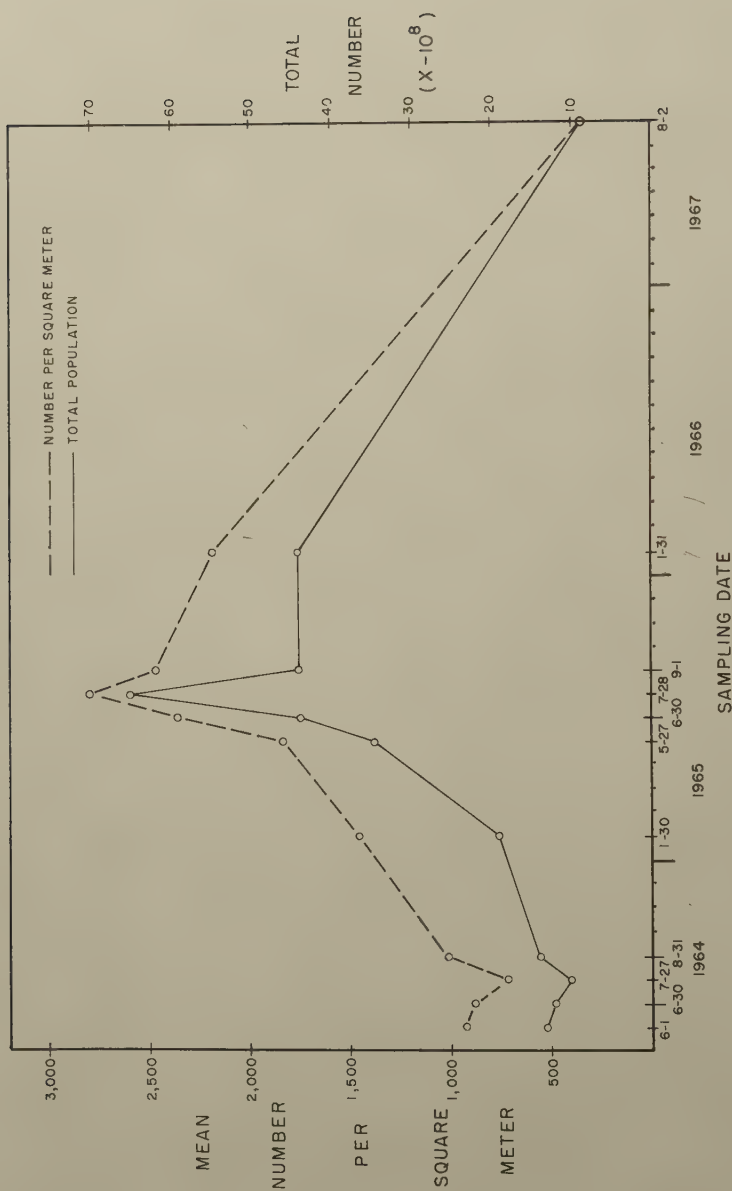


FIGURE 17. Estimated total numbers and mean densities of chironomid larvae for the entire reservoir.

rich in suitable foods. Oxygen is recognized as an important limiting factor for nematodes (Crofton, 1966), although some species have been found in anaerobic lake habitats (vonBrand, 1960). Deep lakes generally have a poor fauna except at their margins. Anaerobic conditions associated with thermal stratification can be "completely inimical" (Crofton, 1966).

The very low nematode densities in August 1967 (Figure 15) when the lake was stratified again, are difficult to explain.

The changes which occurred in clam distribution during the study period are those one would expect of a newly introduced sessile organism with a clearly defined annual spawning season and pelagic larvae.

The distribution and abundance of midges can be strongly influenced by diseases, parasites, predators (Hilsenhoff, 1967) and migrations away from unsuitable environments (Bay, Ingram, and Anderson, 1966). Similar biotic factors must also influence the distribution of oligochaetes, clams, and nematodes. The similarities in responses of all four groups suggest that abiotic changes associated with destratification were primarily responsible for the big changes in abundance in the profundal zone during the study period.

Fishery Management Implications

Midge larvae are important as food for warmwater fish (Calhoun, 1966b). Extending midge distribution throughout the lake should therefore increase their food supply. The changes in distribution of tubificids, clams, and nematodes should have little direct effect, since they do not usually enter food chains culminating in game fish.

The marked changes in the hypolimnion of El Capitan Reservoir caused by artificial destratification may have significant long-term implications. Higher temperatures and oxygen concentrations, coupled with the great increase in the numbers of detritus-feeding bottom organisms, must have substantially increased the chemical and biological degradation of organic materials in the deeper portions of the lake. These changes alone may suffice to explain the apparent shift toward oligotrophy in 1967 (Fast, 1968), although the shift was so slight that it could be due to a normal yearly variation.

In 1964, before the experiment began, the lake was anaerobic below 10 m by early June (Fast, 1968). In August 1967, after 4 months of stratification, the hypolimnion still contained a trace of oxygen. This may be a result of artificial destratification during the preceding summers, but the increase in reservoir volume during the study period provides an alternative explanation. Long-term trends in limnological conditions in similar reservoirs which are destratified artificially should prove of interest. If the process does indeed retard or reverse the natural eutrophication process in such waters, it will tend to make them less productive. R. M. Jenkins (Stroud, 1969) found a negative correlation between total fish crops and thermocline depth in a series of hydropower reservoirs. On the other hand, changes in the higher levels of the food chain associated with better environmental conditions for fish in the hypolimnion—for example, the increases in availability of food organisms and in living space for fish in summer—might more than counterbalance a minor decrease in primary productivity. The

artificial fertilization of lakes has generally not improved sport fishing in North America except in small, warmwater reservoirs in the southeast where low natural fertility of the lateritic soils limits the available nutrients severely (Calhoun, 1966a). Sport fish are several trophic levels removed from the direct influence of primary productivity and baffling variables and interactions confuse relationships between such productivity and game fish production (Rupp and DeRoche, 1965; Nicola and Borgeson, 1970).

Little is known of the ecological factors controlling fish production in warmwater reservoirs. Several years' experience with destratification in various southern California water supply reservoirs has given no indications of immediate adverse effects on the fisheries. It may be a long time before its long-term implications are fully understood. Meanwhile, immediate problems centering around water quality will probably dominate the management of reservoirs like El Capitan. For example, artificial destratification may be a good alternative to repeated heavy treatment with copper sulfate for maintaining acceptable drinking water quality. The latter can have obvious and immediate detrimental effects upon fish populations, far worse than anything to be expected from destratification.

REFERENCES

- Anderson, R. O. 1959. A modified flotation technique for sorting bottom fauna samples. *Limnol. and Oceanog.*, 4 (2) : 223-225.
- Augenfeld, J. M. 1967. Effects of oxygen deprivation on aquatic midge larvae under natural and laboratory conditions. *Physiol. Zool.*, 40 (2) : 149-158.
- Bay, E. C., A. A. Ingram and L. D. Anderson. 1966. Physical factors influencing chironomid infestation of water-spreading basins. *Ann. Entomol. Soc. Amer.*, 59 (4) : 714-717.
- Brinkhurst, R. O. 1965. The biology of the Tubificidae with special reference to pollution, p. 57-65. *In* C. M. Tarzwell (ed.) Biological problems in water pollution, 3rd Seminar, 1962. U. S. Dept. Health, Educ., and Welfare, Taft Sanitary Eng. Center, Cincinnati. 424 p.
- Brinkhurst, R. O., and B. Walsh. 1967. Rostherne Mere, England, a further instance of guano-trophy. *Jour. Fish. Res. Bd. Canada*, 24 (6) : 1299-1313.
- Calhoun, A. 1966a. Habitat protection and improvement, p. 40-47. *In* Alex Calhoun (ed.) Inland fisheries management. Calif. Dept. Fish and Game, Sacramento. 546 p.
- Calhoun, A. (Ed.). 1966b. Inland fisheries management. Calif. Dept. Fish and Game, Sacramento. 546 p.
- Crofton, H. D. 1966. Nematodes. Hutchinson Univ. Library, London. 160 p.
- Curry, L. L. 1965. A survey of environmental requirements for the midge, p. 127-141. *In* C. M. Tarzwell (ed.) Biological problems in water pollution, 3rd Seminar, 1962. U. S. Dept. Health, Educ., and Welfare, Taft Sanitary Eng. Center, Cincinnati. 424 p.
- Eggleton, F. E. 1931. A limnological study of the profundal bottom fauna of certain fresh-water lakes. *Ecol. Monogr.*, 1 (3) : 233-331.
- Fast, A. W. 1968. Artificial destratification of El Capitan Reservoir by aeration. Part 1. Effects on chemical and physical parameters. *Calif. Dept. Fish and Game, Fish Bull.*, (141) : 1-97.
- Ford, M. E. 1963. Air injection for control of reservoir limnology. *Amer. Water Works Assoc.*, 55 (3) : 267-274.
- Hilsenhoff, W. L. 1967. Ecology and population dynamics of *Chironomus plumosus* in Lake Winnebago, Wisconsin. *Ann. Entomol. Soc. Amer.*, 60 (6) : 1183-1194.
- Kennedy, C. R. 1965. The distribution and habitat of *Limnodrilus*. *Oikos*, 16 : 26-38.
- 1966a. The life history of *Limnodrilus udekemianus*. *Oikos*, 17 : 10-18.

- 1966b. The life history of *Limnodrilus hoffmeisteri* and its adaptive significance. *Oikos*, 17 : 158-168.
- Nickerson, H. D. 1961. Gloucester-forced circulation of Babson Reservoir. *Sanitalk*, 9 (3) : 1-10.
- Nicola, S. J., and D. P. Borgeson. 1970. The limnology and productivity of three California coldwater reservoirs. *Calif. Fish and Game*, 56 (1) : 4-20.
- Ogborn, C. M. 1966. Aeration system keeps water tasting fresh. *Publ. Works*, 97 (4) : 84-86.
- Pillai, J. K., and D. P. Taylor. 1968. Biology of *Paroigolaimella bernensis* and *Fictor anchicoprohaga* in laboratory culture. *Nematologica*, 14 : 159-170.
- Rupp, R. S., and S. E. DeRoche. 1965. Standing crops of fishes in three small lakes compared with C-14 estimate of net primary productivity. *Amer. Fish. Soc., Trans.*, 94 (1) : 9-25.
- Slobodkin, L. B. 1962. Growth and regulation of animal populations. Holt, Rinehart and Winston, New York. 184 p.
- Stroud, R. H. 1969. Large reservoir management—Midwest Region. *Sport Fish. Inst., Bull.*, (208) : 1-8.
- vonBrand, T. 1960. Influence of oxygen on life processes, Chapter 27. In J. N. Sasser and W. R. Jenkins (ed.) *Nematology: Fundamentals and recent advances, with emphasis on plant parasitic and soil forms*. Univ. North Carolina Press, Chapel Hill. 480 p.

APPENDIX I

Numbers of Chironomid Larvae¹

Depth (m)	1	3	5	7	9	11	13	15	17	19	21	23	25	27
1 VI 64 ²														
Transect 1	74	109	77	75	37	17	19	7	8	3				
2	125	88	136	33	101	31	1							
3	220	54	157	52	41	32	12							
Mean	47	28	41	18	20	9	4	2	3	1				
N	9	9	9	9	9	9	9	3	3	3				
30 VI 64														
1	200	74	68	46	11	4	2	0	0					
2	158	109	74	2	2	7	1							
3	257	202	176	56	12	0	1							
Mean	68	43	35	12	3	1	--	0	0					
N	9	9	9	9	9	9	9	3	3					
27 VII 64														
1	270	73	36	24	8	3	1	0	0	0				
2	250	84	24	0	0	1	0							
3	164	88	122	9	1	0	0							
Mean	76	27	20	4	1	0	0	0	0	0				
N	9	9	9	9	9	9	9	3	3	3				
31 VIII 64														
1	164	112	70	74	3	2	1	0	0	0				
2	384	260	122	5	1	49	0							
3	251	104	43	22	1	0	0							
Mean	89	53	26	11	1	6	--	0	0	0				
N	9	9	9	9	9	9	9	3	3	3				
30 I 65														
1	79	125	143	142	136	68	38	26	14	9				
2	41	90	107	9	55	96	219							
3	416	189	162	63	61	42	13							
Mean	60	45	46	24	28	23	30	9	5	3				
N	9	9	9	9	9	9	9	3	3	3				
27 V 65														
1	199	134	166	172	138	72	69	24	9	0				
2	1135	248	168	66	28	27	26	5	6	8	9	4	0	
3	699	282	77	68	101	145	66	34	15	8				
Mean	136	74	46	34	27	31	16	8	4	3	2	1	0	
N	15	9	9	9	10	8	10	8	7	6	4	3	1	
30 VI 65														
1	2127	449	408	220	106	66	6	37	10	2	3	1	0	
2	987	70	254	149	34	20	12	5	2					
3	549	216	82	99	43	13	4	6	0	10				
Mean	229	82	74	52	20	11	3	5	2	2	1	1	0	
N	16	9	10	9	9	9	8	9	7	6	3	2	2	
28 VII 65														
1	2981	413	336	184	252	217	212	170	95	100	62	23		
2	340	277	407	360	256	201	135	63	5					
3	478	324	54	34	119	112	41	8	3	0				
Mean	253	92	80	83	70	59	39	30	13	17	21	8		
N	15	11	10	7	9	9	10	8	8	6	3	3		
1 IX 65														
1	405	367	264	189	152	130	112	149	144	109	90	78		
2	255	339	127	284	117	100	123	98	28					
3	483	146	26	61	150	105	35	26	0					
Mean	127	95	46	59	47	37	30	30	19	36	30	26		
N	9	9	9	9	9	9	9	9	9	3	3	3		
31 I 66														
1	269	358	893	105	214	220	228	93	33	25	55	59	97	
2	121	78	46	10	30	60	49	138	190	195				
3	320	158	102	136	107	100	104	141	140	52				
Mean	59	74	87	36	39	48	42	42	37	40	11	20	24	
N	12	8	12	7	9	8	9	10	9	7	5	3	4	
15 VII 66														
1	184	209	105	148	93	103	71	100	59	52	22	15	26	55
Mean	61	70	35	49	31	34	24	33	20	17	7	5	9	18
N	3	3	3	3	3	3	3	3	3	3	3	3	3	3

APPENDIX I—Continued
Numbers of Chironomid Larvae ¹

Depth (m)	1	3	5	7	9	11	13	15	17	19	21	23	25	27
2 VIII 67														
1	101	40	59	1	0	2	2	2	2	0	2	0	0	0
2	216	32	200	1	1	2	0	0	0	0				
3	236	71	30	3	0	0	0	0	0	0	0			
Mean	43	16	26	1	--	--	--	--	--	0	--	0	0	0
N	13	9	11	10	9	9	9	9	10	9	6	3	3	4

¹ Numbers for each depth interval on each of the three transects represent the sums of all the organisms taken in all the samples on that transect at that depth interval. The usual number sampled was three. The mean figure is the total number of organisms from all samples from all three transects divided by the total number of samples, which is given in the row of figures below the means, headed "N". Means are rounded to the nearest whole number. The graphs were drawn by eye from plots of the means multiplied by 44, which converts sample numbers to numbers per m².

² Roman numeral is the month.

APPENDIX II ^{1, 2}
Numbers of Oligochaetes

Depth (m)	1	3	5	7	9	11	13	15	17	19	21	23	25	27
1 VI 64 ³														
Transect 1	276	429	210	388	464	3	10	15	8	8				
2	501	237	348	295	94	19	4							
3	629	514	250	13	12	187	4							
Mean	156	131	90	77	63	23	2	5	3	3				
30 VI 64 ³														
1	147	374	214	264	191	19	0	0	0					
2	340	350	95	22	72	3	0							
3	999	684	165	173	4	0	0							
Mean	165	156	53	51	30	2	0	0	0					
27 VII 64														
1	60	112	40	6	13	0	0	0	0	0				
2	169	114	59	15	8	0	0							
3	703	740	198	26	0	0	1							
Mean	104	107	33	5	2	0	--	0	0	0				
31 VIII 64														
1	226	105	32	63	14	0	0	0	0	0				
2	45	49	61	0	9	0	0							
3	380	310	188	161	0	0	0							
Mean	72	52	31	25	3	0	0	0	0	0				
30 I 65														
1	254	183	41	212	378	42	36	29	17	46				
2	230	110	52	99	52	9	13							
3	268	160	136	188	1	3	11							
Mean	84	50	25	55	48	6	7	10	6	15				
27 V 65														
1	7	6	48	333	506	97	267	25	2	0				
2	5	100	312	235	96	339	490	126	0	0	0	0	0	
3	31	33	667	617	720	1049	15	0	12	2				
Mean	3	15	114	132	132	186	77	19	2	--	0	0	0	
30 VI 65														
1	24	39	296	340	220	788	63	356	44	5	30	32	19	
2	16	2	154	391	65	536	330	30	19					
3	89	102	218	431	1046	446	119	19	5	32				
Mean	8	16	67	129	148	197	64	45	10	6	10	16	10	
28 VII 65														
1	328	166	294	246	594	942	1609	1212	391	610	587	350		
2	1	4	40	1481	1059	526	1449	997	203					
3	213	343	1415	922	1973	3290	1186	74	150	34				
Mean	36	47	175	378	403	529	424	285	93	107	196	117		
1 IX 65														
1	151	140	562	677	620	1276	1536	248	343	559	342	533		
2	221	15	85	918	802	511	629	649	360					
3	972	817	1584	2494	2723	2627	519	395	26					
Mean	149	108	248	454	461	490	298	144	81	186	114	178		
31 I 66														
1	94	224	344	63	233	204	394	497	488	377	561	206	103	
2	203	18	9	56	101	60	64	113	257	33				
3	50	316	472	1138	751	661	437	181	46	3				
Mean	29	70	69	180	121	116	99	79	88	59	112	69	26	
15 VII 66														
1	199	116	247	266	131	123	92	580	580	405	238	190	615	313
Mean	66	39	82	89	44	41	31	193	193	135	79	63	205	104
2 VIII 67														
1	749	124	185	65	2	5	2	5	37	22	92	179	703	587
2	260	110	281	22	48	162	23	9	17	17				
3	712	374	358	175	243	1182	254	195	404	14	84			
Mean	132	68	75	26	33	150	31	23	46	6	29	60	234	147

¹ See footnotes Appendix I.² Appendix I gives numbers of samples at each depth.³ Nematodes were included with oligochaetes in samples of June 1 and June 30, 1964. Numbers were too small to affect oligochaete data significantly, judging from numbers of nematodes on July 27, 1964.

APPENDIX III ^{1,2}

Numbers of Clams

Depth (m)	1	3	5	7	9	11	13	15	17	19	21	23	25	27
1 VI 64														
Transect 1	0	0	0	0	0	0	0	0	0	0				
2	2	0	0	0	0	1	0							
3	0	0	0	0	0	0								
Mean	0	0	0	0	0	0	0	0	0	0				
30 VI 64														
1	0	0	4	0	0	0	0	0	0					
2	1	1	0	0	1	0	0							
3	0	0	0	0	0	0	0							
Mean	--	--	--	0	--	0	0	0	0					
27 VII 64														
1	0	0	0	0	0	0	0	0	0	0				
2	0	0	29	0	0	0	0							
3	0	0	0	0	0	0	0							
Mean	0	0	3	0	0	0	0	0	0	0				
31 VIII 64														
1	0	0	1	0	0	0	0	0	0	0				
2	5	38	16	0	0	0	0							
3	0	0	0	0	0	0	0							
Mean	1	4	2	0	0	0	0	0	0	0				
30 I 65														
1	0	0	12	4	1	0	0	0	0	0				
2	28	190	146	178	2	3	1							
3	2	0	2	2	0	0	0							
Mean	3	21	18	20	--	--	--	0	0	0				
27 V 65														
1	0	0	1	65	234	192	6	1	1	1	0	0	0	
2	0	0	0	0	1	0	0	0	1					
3	0	0	0	0	2	2	0	0	1	0				
Mean	0	0	--	8	24	24	1	--	--	--	0	0	0	
30 VI 65														
1	0	0	0	2	4	0	0	0	0	0				
2	2	0	9	23	107	36	0	0	0					
3	0	0	0	0	0	1	0	0	0	0				
Mean	--	0	1	3	12	4	0	0	0	0				
28 VIII 65														
1	0	0	0	0	0	0	0	0	0	1	0	0		
2	3	0	23	25	10	76	5	0	0	0				
3	0	0	0	0	0	0	0	0	0	0				
Mean	--	0	2	4	1	8	1	0	0	--	0	0		
1 IX 65														
1	0	0	0	1	1	7	0	0	0	0	0	0		
2	1	14	87	65	57	23	1	0	0					
3	6	0	4	0	0	0	0	0	0					
Mean	1	2	10	7	6	3	--	0	0	0	0	0		
31 I 66														
1	0	0	10	3	56	107	86	21	4	1	20	8	10	
2	1	25	96	72	158	65	260	34	43	19				
3	0	0	0	0	4	26	12	5	18	3				
Mean	--	3	9	11	24	25	40	6	7	3	4	3	3	
15 VII 66														
1	6	0	26	0	14	16	15	6	7	2	1	7	7	8
Mean	2	0	9	0	5	5	5	2	2	1	--	2	2	3
2 VIII 67														
1	3	60	66	0	0	1	1	9	10	5	22	9	13	63
2	45	201	112	0	0	0	2	3	3	2				
3	0	0	0	0	0	0	1	1	0	3				
Mean	4	29	16	0	0	--	--	1	1	1	4	3	4	16

¹ See footnotes Appendix I.² Appendix I gives numbers of samples at each depth interval.

APPENDIX IV^{1,2}

Numbers of Nematodes

Depth (m)	1	3	5	7	9	11	13	15	17	19	21	23	25	27
27 VII 64														
Transect 1	32	6	5	7	0	0	0	0	0	0				
2	4	0	0	0	0	0	0							
3	11	1	6	4	1	0	0							
Mean	5	1	1	1	--	0	0	0	0	0				
31 VIII 64														
1	3	12	6	34	5	0	0	0	0	0				
2	26	11	17	4	0	0	64							
3	2	1	8	0	0	0	0							
Mean	3	3	3	4	1	0	7	0	0	0				
30 I 65														
1	0	0	0	0	0	0	0	0	0	0				
2	4	3	5	0	0	0	0							
3	3	0	0	0	0	0	0							
Mean	1	--	1	0	0	0	0	0	0	0				
27 V 65														
1	0	0	0	27	64	0	0	0	0	0				
2	0	0	0	3	21	0	4	0	0	0	0	0	0	0
3	23	0	2	1	6	6	1	0	0	0				
Mean	1	0	--	3	9	1	1	0	0	0	0	0	0	0
30 VI 65														
1	27	11	14	0	12	19	0	0	0	0	0	0	0	0
2	0	0	0	19	9	3	2	0	0	0				
3	31	26	8	0	28	10	0	0	0	0				
Mean	4	4	2	2	5	4	--	0	0	0	0	0	0	0
28 VII 65														
1	236	130	119	8	47	68	102	20	2	0	0	0		
2	0	0	4	73	496	23	78	0	0					
3	72	26	1	3	0	14	14	2	0	0				
Mean	21	14	12	12	60	12	19	3	--	0	0	0		
1 IX 65														
1	23	14	6	0	0	14	15	3	9	5	1	3		
2	0	0	12	170	202	46	35	4	20					
3	328	419	3	0	23	20	0	4	0					
Mean	39	48	2	19	25	9	6	1	3	2	--	1		
31 I 66														
1	0	4	91	10	29	4	23	6	7	0	0	0	0	0
2	0	0	0	3	40	13	21	0	0	0				
3	0	39	0	0	0	5	0	0	0	0				
Mean	0	5	8	2	8	3	5	1	1	0	0	0	0	0
15 VII 66														
1	0	8	13	6	34	16	7	21	0	7	12	0	1	1
Mean	0	3	4	2	11	5	2	7	0	2	4	0	--	--
2 VIII 67														
1	1	0	0	0	0	2	0	0	0	0	2	1	0	0
2	5	0	0	0	0	0	0	0	0	0				
3	5	0	0	2	0	0	0	0	0	0	0			
Mean	1	0	0	--	0	--	0	0	0	0	--	--	0	0

¹ See footnotes Appendices I and II.² Appendix I gives numbers of samples at each depth interval.

